

# A Model for Spatial Monitoring of Exhaust Gas Emissions Produced by Urban Public Transport

Gustavo Olguín<sup>1</sup>, Alejandro Mesa<sup>\*2</sup>

<sup>1</sup>Facultad de Ingeniería, UTN, Regional Cuyo, Mendoza, Argentina <sup>2</sup>INCIHUSA, CONICET, CCT Mendoza, Argentina.  
<sup>1</sup>*g\_stavomza@hotmail.com*; <sup>\*2</sup>*amesa@mendoza-conicet.gob.ar*

**Abstract-** This study describes the development of a mock model of exhaust pipe emissions from the Urban Public Transport System (UPTS). The aim is to use this tool to calculate and monitor emissions produced by the UPTS vehicles that circulate in an established area. The model enables the user to determine the emission produced by STPP units (global and separated by its chemical and physical components in grams), per area unit (cell) and in a period of time (day or hour), both values established by the user. The calculated methodology is described, and simplified examples of the calculations are presented.

**Keywords-** Exhaust Gases Emissions; Predicting Mod; Urban Public Transport

## I. INTRODUCTION

When analyzing the factors that weigh in on urban air quality, it becomes evident that internal fuel engines are the main source, on an urban scale, of carbon monoxide emissions. These plus hydrocarbons, nitrogen oxides and toxic substances, such as particles and lead, all have a noxious effect on health. This problem arises within modern day cities due to the increasing number of vehicles, and their normal deterioration that, consequently produce high levels of pollution.

The intensity of this alteration depends partly on the city morphology, and how it is related to the dimension of its roadways. Another factor to be considered is the city physiology, directly related to the anthropogenic activities that include the interaction of transport, industrial activity, people's movements, poor ventilation, and the characteristic micro climate of the city [1].

The concentration of certain substances in the air in many places (main ways and downtown) exceeds the allowed maximum limit which produces permanent environmental impacts and endangers people's health [2, 3, 4]. In this context, the Urban Public Transport System (STPP) must be evaluated, because despite being a major source of environmental pollution [5, 6, 7, 8] represents the alternative modal shift from private car, thus reducing the number of sources stations [9, 10].

Therefore, the purpose of this work is to point out that it is essential to have tight control over mobile emissions, and that the STPP is a system that can initiate ways of control and evaluation due to its special characteristics [11, 12, 13, 14, 15].

### A. Principal Antecedents

On an urban level, models for air polluting calculation are generally focused on fixed sources (e.g. industrial facilities, houses), considering that in these cases it is easier to identify the source and estimate the total emissions.

When attempting to evaluate emissions factors in a dynamic system such as the UPTS, the situation changes due to mobile sources, because variations are given not only in a temporal but in a spatial scale [16, 17].

Regarding this, Martínez Pérez and Monzón de Cáceres [18, 19] analyze the air quality in Spanish cities according to current European norms, and without developing a model, obtain significant results comparing vehicle emissions to levels of current contamination.

Shir and Shieh [20] present a generalized model to calculate the urban atmospheric pollution based on the numerical integration of the concentration equation, which was developed for the study of air pollutants distribution in an urban area. The model calculates the distribution in a temporal and dimensional way resulting from the spatial concentration of multiple points and sources, applying existent weather forecast data as well as origin data.

Aiming at predicting the impact of urban morphology over the air quality in urban streets, Hong Huang [21] developed a bi-dimensional numeric model using atmospheric diffusion equations for vehicle emissions. The numeric model was consolidated using the data base of a set of experiments that evaluates the behaviour of different typical canon designs of existent cases. Vienneau, de Hoogh, and Briggs [22] generate high-resolution mapping of air pollution using a GIS-based moving window approach.

A useful evaluation model is SCREEN3 (EPA 450/4-9-006) Orientation Modeling, and EPA 454/R-92-019, evaluation methods for fixed sources. This point of view does not require any entry for specific forecast data, since the calculations are made for a spectrum of possible wind speed combinations and the stable atmosphere. The model determines the greatest concentrations in relation to the wind direction and its intensity taking into account a basic built environment [23].

For an estimate result in more complex areas, the CTSCREEN model is available. As it only considers one emission source, in the case of multiple nearby sources, the model allows their input by the sum of emissions rate of those sources as the total emission source origin rate. This shows an overall estimation, since the geographic separation effects between the sources or the points of greatest concentration are not considered.

UK ADMS-Roads models is a complete tool for calculating air pollution related to road networks and industrial sites, and is able to calculate emissions from traffic flow for different scenarios and time periods, with links to GIS programs [24]. Other current models are the ISC3, el CTDMPLUS, the DESFILE developed by Electricité de France, the Penacho 5, developed by Pacific Gas & Electric Co. and the German system TA Luft. All these examples are focused on the fixed sources of urban pollution.

## II. METHODOLOGY DESCRIPTION OF MODEL CALCULATION

When the development of the model was considered, the main objective was for it to be dynamic, precise and, above all, easy to use. The presented model is a pre-diagnostic tool in the incidence of PP transport emissions on the conditions of air pollution from various sectors of an urban area. It is worth noting that the aim of the model must be completed with additional information, as it was designed to support a strategic transport system plan but not a local emission measurement objective.

Through this study the disintegrated fuel emission values can be obtained, using chemical and physical components produced by the UPTS vehicles as they move over a region covered by the service (a general area or specific sector), in a period of time (day, hour or minutes) specified by the user.

The model is structured on a sequence of written calculated modules in Fortran language, that solves the incidence of each of the independent UPTS variables. Each module processes a set of primary data that must be included in a specific format based on their own characteristics. The first set corresponds to parameters that describe the geographic place of analysis. The second bundle of data utilizes all the parameters and relative variables to the UPTS (Fig. 1).

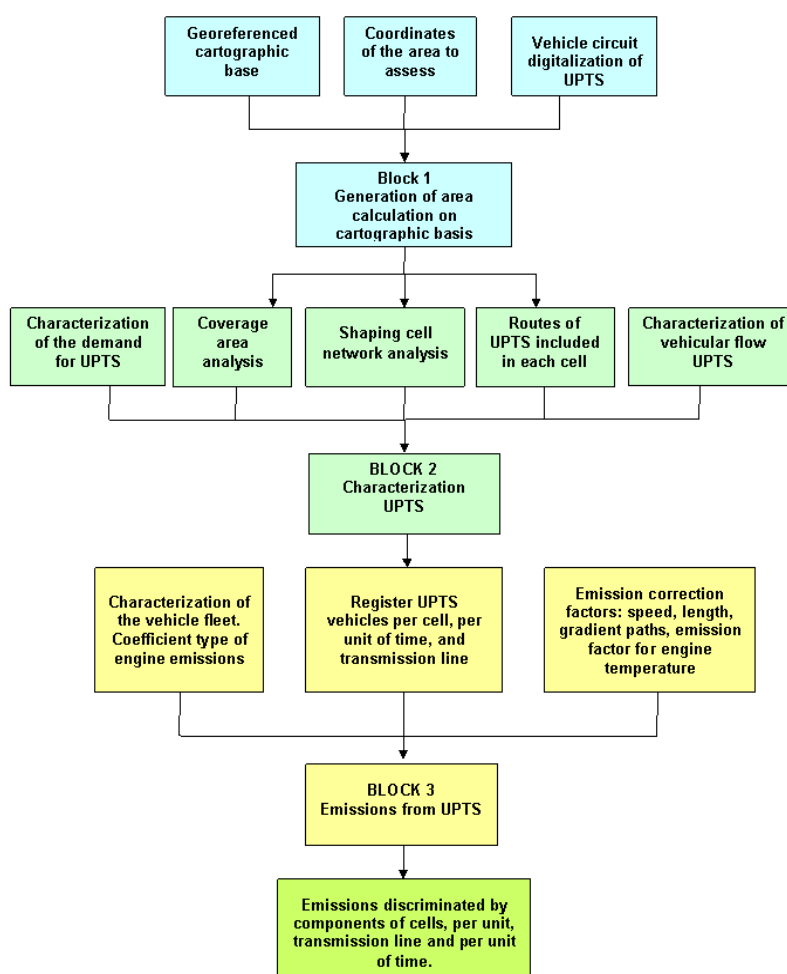


Fig. 1 Conceptual proposed model

Considering the complexity of the problem, the system is conceptualized in an application that solves the parameter and variable multiplicities from various elements (space, time, technology, users behaviour) simultaneously to obtain the expected

result.

This system takes form with the following expression:

$$\Phi_{(a,t,b,j,f,v,r,u)} = E_{(a,t,b,j,f,v,r,u)}^{(NOx,CH_4,VOC,CO,N_2O,PM,CO_2)} \quad \text{eq. (1)}$$

$\Phi_{(a,t,b,j,f,v,r,u)}$ : This is the result of a set of essential model elements that solves the emission considering, simultaneously, the characteristics of the covered area divided by a cell (a), state of the system in a determined moment (t), number of vehicles (j) amount of fuel used (b), time frequency (f), vehicle speed (v), the circuit (r) of the buses and the passengers (u) that go into the UPTS.

$E_{(a,t,b,j,f,v,r,u)}^{(NOx,CH_4,VOC,CO,N_2O,PM,CO_2)}$ : This is the emission determined by its components, produced by the UPTS for a determined area, considering the boarding conditions function  $\Phi$ .

The main model characteristics can be summarized in the following points:

- It establishes that the result is a simulation process of a typical working UPTS day in a selected region.
- It establishes the answer according to possible frequency or circuit changes enabling the input of public unreal transport circuits to quantify the incidence of changes or new UPTS circuits.
- It shows the results on a micro scale according to time and/or space (meter/ second).

Compatible platform for calculating public modules of the International organizations (EPA, CORINAIR, etc.): this allows updating of physical parameters of fuel emissions produced by the combustion chambers of the vehicle engines.

Easy adaptability to the different UPTS characteristics evaluating the heterogeneity and age of models, frequency and speed circuits and the supporting network structure and disaggregated emission values obtained by its components (chemical and physical) without localized monitoring requirements.

#### A. Minimum structural computer processing

The emission analysis can be carried out for the whole integrated UPTS in a section of the circuit or in a selected micro urban sector.

##### *Block 1 Cartographic basis: Topographical plan of the evaluation space.*

The determination of the analysis network is done by the graphic input of a set of points that represent all the road intersections in an urban sector. This forms the macro-cartographic basis evaluation model that can be seen through CAD, GIS and compatible systems.

From the created database, a text file is obtained by an input process in chart format: the number of lines that the file contains is indicated on the first line and column (this is in relation to the evaluated dimension area and the determination of the minimum analysis scale). From the second line downward, the column data is being completed, initiating by each code point, x, y, z. The z input allows the tridimensional characterization basis of the model on which the UPTS moves and how its effect over the emission will be later evaluated.

The other columns show the identification zones and sub-zones to which that point corresponds, and the information of identified stop signs and traffic lights. The zones and sub-zones are territory areas defined by a statistic indicator that refer to the average intended trips according to a sample number of passengers.

Those zones and sub-zones are established beforehand by the user inside the cartographic basis and they can correspond to administrative divisions or any other useful sub-division (Table 1).

TABLE 1 MATRIX OF RELATION TO THE ANALYSIS UNIT SCALE

Code point	X	Y	Z	Zones and Sub-zones							
OF4G-AMOP	2514647.75	6352116.2	926.8	0	0	1	157	0	0	0	0
OF4G-AMIY	2515106.75	6352557.5	945.2	0	0	1	158	1	0	0	1
OF4G-AMTG	2515591.75	6353001.0	987.1	0	1	1	160	0	1	1	1
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"

The number of lines in this matrix is in relation to the analysis unit scale (cell and sub-division area).

##### *Block 1 Cartographic basis: Vehicle circuit digitalization.*

Considering the cartographic network as the basis, the following steps consist of the vehicle UPTS digitalization circuits.

The different system trajectories are defined by the topographical coordinate order of the nodes that integrate each circuit. The sum of all the circuits compounds the UPTS network trajectories. The trajectory circuit longitude is determined by the sum of all the circuits between nodes that integrate a distance.

This action is done by highlighting the correlative points of the different trajectories of all the UPTS circuits on the generated cartographic basis.

### *Block 1 Cartographic basis: Area analysis generation.*

Two coordinates are set on the cartographic basis, corresponding to the left inferior vertex ( $X_{min}, Y_{min}$ ) and right superior ( $X_{max}, Y_{max}$ ) of the rectangular region where the study is expected to be carried out.

Selecting this point as the start and drawing a diagonal line from the starting point to the right superior extreme as the final point, and adjusting the sub-division lineal dimension, the necessary data is obtained to automatically generate the sub-division area. This has to do with a list of coordinates that are the trajectories of all the UPTS buses corresponding to each sub-division area (1).

With the user defining the minimum analysis unit dimension, the model establishes the amount of cells and re-calculates the previously established coordinates, determining the monitoring area that will be formed by a topographical matrix. In this way a regular sub-division area is automatically built, with a smallest unit equal to one meter.

In Figure 2, three UPTS trajectories are exemplified, and the streets are simplified, leaving only the points that are intersections, where each cell is identified with a code. The sub-division area vertexes do not necessarily coincide with the intersection points and thus, being determined as the referential zones, where information of global or partial emission indexes will be obtained.

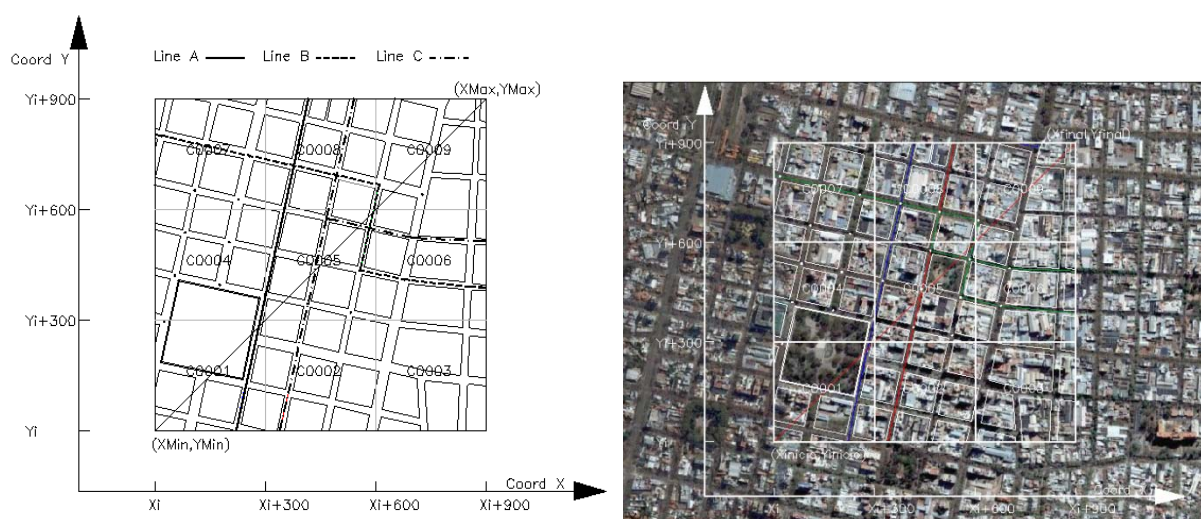


Fig. 2 Topographical net and covered area scheme

Having the analysis cells defined, the model automatically calculates which trajectory segments of the UPTS lines are included in each analysis unit.

The generation of coordinates that covers the analysis area is kept in a file that enables the selection of a set of points, which are joined, to define possible circuit trajectories. That is to say, the partial longitude trajectories kept in each analysed area will be used, taking the cell as the minimum unit, and also defining regular zones that are smaller than the ones given by the evaluated sector files of zones and sub-zones (see point Topographical plan of the evaluation space)

Once the analysis zone is determined, the model identifies which circuit and UPTS line is included in that area and, at the same time, which ones are included in each cell.

Then, those points that do not correspond to any trajectory must be filtered out, defining the sub-division area in a point where coordinates are sufficiently secure and where all the system trajectories are included. This process is possible by a simple plan inspection that contains all the drawn system trajectories, opened from AutoCadR (see point Vehicle circuit digitalization).

Whit the evaluated area being defined, each UPTS frequency unit and the total number of vehicles of each line that passes through in a simulation day can determine the total circuit longitude in each sub-division, fixing the time as the pattern of the analysis sequence.

The magnitude that expresses the total UPTS extension is:

$$R_{a_s}^{\text{UPTS}} = \sum_{m=1}^{M_{a_s}} \sum_{c=1}^{N_{a_s}} r_c^m \quad \text{eq. (2)}$$

Being:

$R_{a_s}^{\text{UPTS}}$  : The total UPTS circuit trajectory sum of an area.

$r_c^m$  : Trajectory circuit in a cell and corresponding to a STTP traffic lane.

$a_s$  : Covered analysis area  $s=1,2, \dots$

$m$  : Traffic lane index,  $m=1,2,\dots M_{a_s}$

$M_{a_s}$  : Total amount of traffic lanes in  $a_s$

$c$  : Cell index,  $c=1,2,\dots N$

$N_{a_s}$  : Total amount of cell in  $a_s$

As a result of the Block 1 processing, the covered analysis area is obtained divided in cells and shown parallel to all the UPTS circuit lines.

### *Block 2 UPTS Characterization Demand.*

Block 2 is built by adding the number of passengers, the frequency that vehicle enter and exit the system from Block 1.

The calculating emission model characterizes the UPTS demand by obtaining origin-destiny matrix data (MOD) 2. This information is composed from the distribution of passenger journeys with an origin in a sub-zone i-... and a sub-zone j-... destiny [25].

Data coming from MOD allows the model to distribute the passengers over the cartographic basis (the UPTS stops) in a determined zone and time. The demand incidence in the emission model is given by the period of time that each person stays inside the system. When it is over automobiles, it affects the variable number of passengers in the vehicle tare, and when it is at a commuting station it affects the bus starts and stops factor.

Commuting shows the necessity of the system and it is taken into account in the final intended destination. The total of all the necessary trajectories are considered to satisfy each UPTS passenger's final destination. All these characteristics affect the final emissions: the road gradient, the vehicle's power and the speed related to the variable cargo.

### *Block 2 Determination of Vehicle Frequency.*

Frequencies: the input frequency data is carried out by inserting a matrix format file, the first column of which describes each line of transport, and the following columns are formed with the departure schedule of each vehicle, in units of time (minimum unit: 1 second), inserting a lapse of time for entering the UPTS (in seconds).

Speed: taking into account the distance trajectory basis and the time determined by the UPTS that each circuit demands, the medium speed was considered for the operation.

Considering these values and the ones previously entered, the model enables us to know the location in space and time of each unit included in the UPTS. The speed of the system works according to the type of route (urban, rural and highway), thus pondering the UPTS emission coefficients. Likewise, the average speed of the system varies according to the schedule considered, which is directly linked to traffic congestion and number of travelers.

### *Block 3 UPTS Obtained Emissions Vehicular Characterization.*

The regulations for motor manufacturing create the progressive decrease of emission. Moreover, in some countries the use of old vehicles and poor maintenance determine heterogeneous characteristics of the public transport system.

The model allows the consideration of the vehicular heterogeneity that generally composes the UPTS, in relation to the engine type and age. All these variables affect the fuel factor emission produced by each vehicle.

### *Block 3 UPTS Obtained Emissions Methodology for calculating fuel pollutant emission factors*

The developed methodology considers that certain emission values are due to two different situations. The first considers the total annual emissions, taking into account the circuit distances, average speed and fuel consumption, and considers the

total annual averages of all these values. The second gives us information about point by point emission values taking into account the right vehicular distance, instantaneous speed of that unit, and the number of passengers included in the system per minute.

Considering as necessary inputs the type of vehicle, the speed range and corresponding emission factor (g/km), the model is compatible with different international normative value formats like the CORINAIR and the Environmental Protection Agency (Table 2).

The emission factors given by these organizations create a static reference for type of vehicle and type of landscape, but the option also exists for those values to be updated if motor fuel technology used by the UPTS changes.

TABLE 2 EMISSION FACTOR ESTIMATE FOR HEAVY DUTY VEHICLES (URBAN BUSES)

	NO <sub>x</sub>	CH <sub>4</sub>	VOC	PM	CO	N <sub>2</sub> O	CO <sub>2</sub>
<b>Total g/km</b>	10.4	0.06	2.01	0.235	8.98	0.03	774
<i>Considered average consumption: 29.9 l/100km</i>							

Considering the methodology recommended by the Environmental Protection Agency [26], the design develops the calculation of the emission value factors, taking into account the longitude distance (km) by a vehicle or by its consumption (kg fuel).

In the first case the emission factor corresponds to:

Emission (g)= emission factor (g/km) \* fraction of distance (km)

Read Row 1 of Table 1. The emission factors can be modified from [g/km] to [g/kg fuel] using vehicle consumption data and type of roads.

If fuel consumption is used:

$$E_{\text{hot}; i, j, k} = g_{j, k, l} \cdot b_{j, l} \cdot e^*_{\text{hot}, \text{year}, i, j, k} \quad \text{eq. (3)}$$

Where:

$E_{\text{hot}; i, j, k}$  = emission of the pollutants i in (g)

$g_{j, k, l}$  = share of annual fuel consumption of type i used by vehicles of category j, driven on road type k

$b_{j, l}$  = total annual consumption of fuel type i in (kg) by vehicles of category j operated in reference year

$$b_{j, l} = \sum_{k=1}^3 m_{j, k} \cdot c_{j, k} \quad \text{eq. (4)}$$

$c_{j, k}$  = fuel consumption average in (g/km) in a vehicle category j on a type of road k

$e^*_{\text{hot}, \text{year}, i, j, k}$  = average fleet representative baseline emission factor in (g/kg fuel) for the pollutant i, relevant for the vehicle category j, operated on roads of type k with hot engines.

I (pollutants)= 1-10 for the pollutants covered

j (vehicle category)= 1-83 for the on-road categories defined in the vehicle category split

K (road classes)= 1-3 (1= urban, 2= rural, 3= highway) (note that the road types implied certain speed patterns)

The application of equation 4 requires statistical input data which are not available in several countries. Therefore, some data have to be estimated. The factors  $b_{j, l}$  and  $g_{j, k, l}$  used in equation 4 cannot be introduced into the calculation from statistical data they have to be estimated with the help of other parameters.

It is proposed to start with:

$$m_j = h_j \cdot v_j \quad \text{eq. (5)}$$

$m_j$  = total annual mileage in (km) of vehicle category j (in this case it is only one type of vehicle: diesel bus)

$h_j$  = number of vehicles of category j

$v_j$  = average annual mileage driven by each vehicle of category j

Being:

$$m_{j, k} = m_j \cdot d_{j, k} \quad \text{eq. (6)}$$

Where:

$m_{j,k}$  = total annual mileage in (km) of vehicle category j on road class k

$d_{j,k}$  = share of annual mileage driven on road class k by vehicle category j

By this methodology the total mileage is considered on roads where the pollutant emissions are being globalized, without taking into consideration a particular sector, and only taking into account the Diesel Bus vehicle and an urban type of road (20 km/h).

$$g_{j,urbano} = C_{j,urbano} \cdot m_{j,urbano} / \sum_{k=1}^3 C_{j,k} \cdot m_{j,k} \quad \text{para } k = \text{urbano} \quad \text{eq. (7)}$$

Where:

$g_j$  = consumption factor

$C_{j,urbano}$  = average consumption in g/km

$m_j$  = mileage in (km)

Then :

$$e_{hot,año,i,j,k}^* = e_{hot,year,i,j,k} / C_{j,k} \quad \text{eq. (8)}$$

Being:

$e_{hot,año,i,j,k}^*$  = medium relative emission factor to the consumption that represents the base reference for the year considered in (g/kg fuel) by pollutant i of a vehicle of category j on roads of type k with hot engines.

$e_{hot,year,i,j,k}$  = medium emission factor that represents the base reference for the year considered in (g/km) by a pollutant i of a vehicle of category j on roads of type k with hot engines.

$C_{j,k}$  = average consumption in (g/km) of a vehicle of category j on roads of type k. The model especially quantifies the emission by the explicit factors in the previous notes.

All these elements that lead to the emission either by exclusive mileage considerations or by consumption per kilometer can be determined by the model characteristics and the compatibility for this type of standard.

To calculate equation (5):

$h_j$  = Output data of the model.

$v_j$  = Output data of the model.

$m_j$  = It is obtained by a program that calculates the parameter per cells.

To calculate equation (6):

$d_{j,k}$  = It is taken from the model by a program that adds all the mileage of the UPTS units on different types of roads.

### *Block 3 UPTS Obtained Emissions Emission correction factors*

In some places where the all vehicles have heterogeneous characteristics of age and maintenance, and a lack of urban planning that leads to traffic congestion, it is necessary to bear in mind different factors for adjustment to have the closest approximation to reality.

The vehicle mass greatly affects all the correction factors. It was calculated as the total sum of vehicle tare and the variable mass that represents the total weight of estimated passengers, according to the origin-destination matrix that defines the number of passengers per hour and sector that are distributed in a typical day.

The development of the model required the following correction factors:

According to the vehicle's speed: the relative correction factor to the vehicle speed is determine by the different road classification.

The model structure which is compatible with the emission characterization rules allows the speed factor input through two methods:

- The easiest method to consider for an urban road, a rural road, and a highway is an associated speed (20km/h, 60km/h and 100km/h respectively) and apply the emission factor obtained from the tables or with help from the equations.
- The second method is to consider the emissions- speed function by

$$e_{hot,i,j,k} = \int e(z) f_k(z) \quad \text{eq. (9)}$$

$e_{hot,i,j,k}$  = emission factor in (g/km) for the pollutant i, of a vehicle of category j on roads of type k with hot engine.

Z= speed of vehicle according to the type of road (rural, urban or highway).

$e(z)$  = mathematical expression of the speed – dependency emission.

$f_k(z)$  = equation of the frequency distribution of the mean speeds which corresponds to the driving patterns depending on the type of vehicle, road and engine size.

The model makes it possible to obtain the relationship between distance and exact speed plus the respective time of the area under the curve of speed-time-distance of each UPTS bus for the node density of the cartographic basis.

Taking into account the relation between the speed variation and the emissions, variability is possible because of the proper characteristics of the model. Relating the values of maximum and medium speed with the trajectory coordinates of each UPTS unit, the model obtains the emissions of the different node points of each bus circuit with (xi) identifying the line transport to which it belongs and the moment (ti) in which it is produced (Fig. 3).

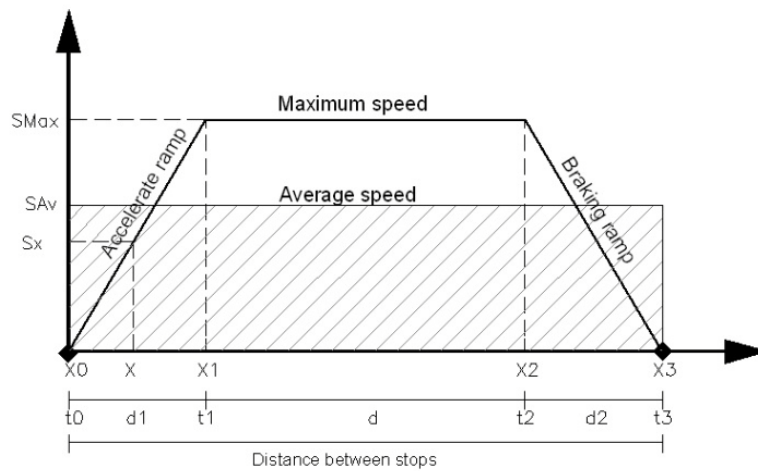


Fig. 3 UPTS speed vehicle ramp.

According to the vehicle's age: considering the heterogeneity of the current vehicles in the UPTS, the engine age of each unit is an unavoidable factor. This is founded on the necessary consideration of emissions produced by engines of different characteristics and the deterioration of the vehicles associated with their age.

The model allows the consideration of a coefficient that summarizes the relative emission variability to the years of the UPTS unit. The value of this correction factor is taken from the international updated standards [27] that consider the following aspects for the calculation: the medium mileage by type of vehicle, the engine deterioration due to its mileage and the level of emission because of the type of engine.

According to cold engine emission factor: there are more pollutant emissions produced during the the period in which the engine is circulating under optimum temperature.

This is determined by the following expression:

$$E_{cold,i,j} = \beta_j \cdot m_j \cdot e_{hot} \cdot (e^{cold} / e^{hot} - 1) \quad \text{eq. (10)}$$

$E_{cold,i,j}$  = cold emission of pollutant i caused by a vehicle of category j (all the pollutants of this type are estimated for urban driving).

$\beta_j$  = fraction of mileage driven by cold engines (or catalyst operated below the light-off temperature)

$m_j$  = total annual mileage of vehicle category j

$e^{cold} / e^{hot}$  = cold to hot ratio of emissions

#### Road gradient influence

The gradient of a road has the effect of increasing or decreasing the resistance of a vehicle's traction, since the power



employed during driving is the decisive parameter for the emissions of a vehicle.

Even in the case of large-scale considerations, however, it cannot be assumed that the extra emission when travelling uphill is compensated by correspondingly reduced emission when travelling downhill. The gradient is illustrated in the model with a detail of 100 meters.

At the beginning, the emissions and fuel consumption of both light and heavy-duty vehicles are affected by road gradient. Nevertheless, the overall gradient effect on the behaviour of light vehicles is very small, lying in the range of uncertainty about the basic emission factors. However, because of their heavier masses, the gradient influence is much more significant in the case of heavy-duty vehicles. Therefore, it was decided to incorporate only the gradient effect on the emissions of heavy-duty vehicles [24]. The model incorporates the incidence of road gradient over the mileage through the topographical plane evaluation of the trajectory mileage that takes part of the UPTS, taken from the cartographic basis.

Fuel consumption is obtained through a sub-routine of the model because each bus requires a special study in order to calculate the instantaneous potential over the trajectory. The minimum necessary information between nodes in order to calculate the road gradient incidence and exact speed on the emissions is the maximum speed, the medium speed (given by the frequency), the variable mass (bus plus passengers), and the distance.

Correction factors are considered to be a function of:

- Vehicle mass
- Road gradient
- Pollutant or consumption
- Main speed of the vehicle

*Format output of the obtained results through the model*

The format output of the obtained results through the calculating emission model is a matrix with detailed trajectory information (global, daily) by an analysis area unit (cell), and by type in a fraction of time with the total mileage in each cell per each vehicle. The pollutant emission vector will be calculated taking into account the following expression where:

$$\begin{bmatrix} NO_x \\ CH_4 \\ VOC \\ CO \\ N_2O \\ PM \\ CO_2 \end{bmatrix} = X_{km,hi} \cdot \begin{bmatrix} 10,4 \text{ g / km} \\ 0,06 \text{ g / km} \\ 2,01 \text{ g / km} \\ 8,98 \text{ g / km} \\ 0.030 \text{ g / km} \\ 0.235 \text{ g / km} \\ 774 \text{ g / km} \end{bmatrix}$$

$x_{km,hi}$  represents the total mileages and time fraction in each cell. The second period vector is the pollutant emission factor, without considering the correction coefficient, and evaluated in annual periods, which implies that they must be reduced according to the time parameter used. The first period vector indicates the total pollutant emissions classified by their types.

This format of data output table will be repeated as many times as the intervals of time need to be known for the pollutant emission calculation, since the temporal intervals of the mileage transport unit in each cell are known. The vehicle mileages of the transport units that integrate the UPTS taken into account will be all those that are input into the model, except those engines that do not accept the proposed hypothesis or have either different fuel consumption or electric origin. If it is necessary, another partial analysis can be done to discriminate each transport lane emission. However, special care must be taken in the correction factors that identify them according to age and maintenance. On the contrary, the difference of emissions would be given by the difference in number of units along trajectories.

### III. EXAMPLE OF CALCULATION

To estimate the scope of the results that the model provides, an urban area of Mendoza City in Argentina, was selected and evaluated. Generation of trajectory lines on the evaluated sub-division area: in the analysis example, we determined an area of 36 km<sup>2</sup>, divided in 9 sectors of 4 km<sup>2</sup> each. By means of the calculating model of Block 2, each cell is associated with the trajectories according to the topographical plane that has the boundary cell as a limit, and then being studied, in particular and in general (figure 4).

Once the analysis area was determined, three UPTS trajectories were identified in which the evaluation of the produced emissions will be carried out by the circulating vehicles over an entire day.

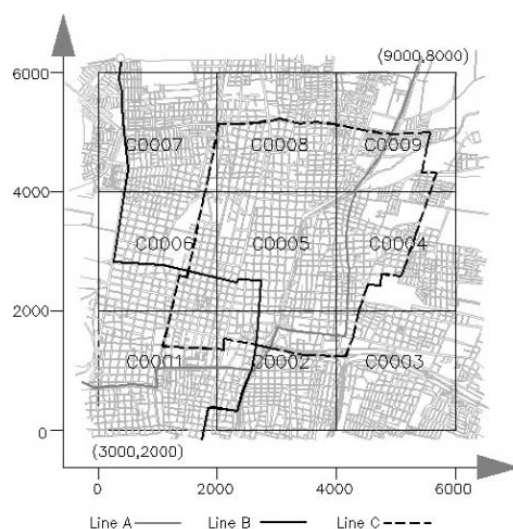


Fig. 4 Distribution of the cells related to the study area.

By means of the calculating model of Block 2, the register is obtained of the UPTS vehicles that circulate on each sector by time unit and transport line. Thus, the mileage is obtained per unit in each cell, of each unit in all the cells through which circulate the total daily mileage and return by each circuit that crosses through the evaluated sector.

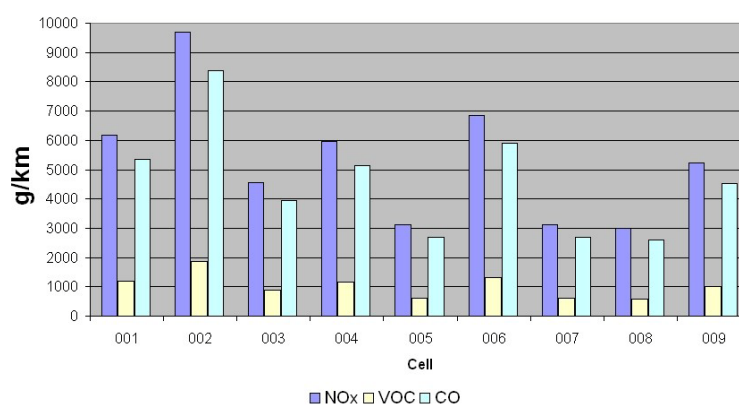
Adding the input values that characterize the vehicles of the zone, the emission coefficients by type of engine and correction emission factors, through the calculating Block 3, the discriminated emissions are obtained by components, cells, unit, transport lane and fraction of time.

The results obtained are presented using tables of values and diagrams that are the synthesis of daily emissions and time fraction of each sector (Table 3, Figures 5-7).

TABLE 3 VALUES OF DAILY EMISSIONS: NO<sub>x</sub>, CH<sub>4</sub>, VOC, CO, PM, N<sub>2</sub>O AND CO<sub>2</sub> PER CELL OF EVALUATED SECTOR

Whole day evaluation time		Emissions by cell (g)								
		1	2	3	4	5	6	7	8	9
km/circuit (total lines)		<b>4.1564</b>	<b>6.5187</b>	<b>3.0681</b>	<b>4.0042</b>	<b>2.1012</b>	<b>4.6062</b>	<b>2.1044</b>	<b>2.0129</b>	<b>3.5141</b>
km/day		594.36	932.17	438.73	572.6	300.47	658.68	300.92	287.84	502.51
<b>NO<sub>x</sub></b>	<b>10.4</b>	<b>6181</b>	<b>9695</b>	<b>4563</b>	<b>5955</b>	<b>3125</b>	<b>6850</b>	<b>3130</b>	<b>2994</b>	<b>5226</b>
CH <sub>4</sub>	0.06	36	56	26	34	18	40	18	17	30
<b>VOC</b>	<b>2.01</b>	<b>1195</b>	<b>1874</b>	<b>882</b>	<b>1151</b>	<b>604</b>	<b>1324</b>	<b>605</b>	<b>579</b>	<b>1010</b>
CO	8.98	5337	8371	3940	5142	2698	5915	2702	2585	4513
<b>PM</b>	<b>0.235</b>	<b>140</b>	<b>219</b>	<b>103</b>	<b>135</b>	<b>71</b>	<b>155</b>	<b>71</b>	<b>68</b>	<b>118</b>
N <sub>2</sub> O	0.03	18	28	13	17	9	20	9	9	15
<b>CO<sub>2</sub></b>	<b>774</b>	<b>460039</b>	<b>721503</b>	<b>339583</b>	<b>443193</b>	<b>232565</b>	<b>509823</b>	<b>232919</b>	<b>222792</b>	<b>3888948</b>

Emission factor (g/km)

Fig. 5 Total daily emissions by sector of NO<sub>x</sub>, VOC and CO.

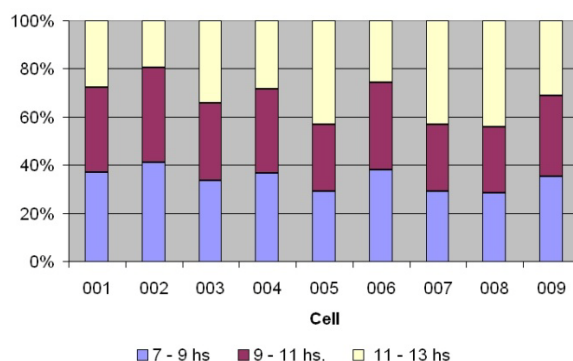


Fig. 6 Percentages of emissions of CO2 by sector for the different fraction of time.

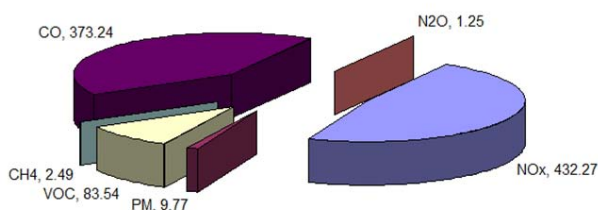


Fig. 7 Emissions corresponding to sector 1 for the fraction of time from 6 to 7 a.m.

The model provides a fast way to pre-diagnose of the incidence of a particular group of vehicles (UPTS) on the air quality of an area. However, the results could not be validated in field measurements, since no traffic lane of the analysed area is exclusive for such vehicles.

#### IV. CONCLUSIONS

The direct consequence of increasing air pollution on an urban scale is verified in recent years by the increasing number of respiratory diseases, and indirectly, by what is known as the urban hot island. By the end of the 20th century, laws were passed encouraging research projects aimed at current engine improvements, the use of cleaner alternative energy sources, and the financial incentive of tax reductions associated with the purchase of non-contaminating vehicles and the use of alternative fuel.

A system of alerts and air quality monitoring in situations of increased or extreme emission levels, is a significant prevention measure, as well as the advance in legislative initiatives that establish air quality standards and restrictions on pollutant emissions in order to protect the health of the general population.

The results obtained from different analyses allow us to believe that the emission calculating model developed here is an important tool to obtain fundamental information quickly and simply, especially in conflicting situations. Through the planning and coordination of UPTS, air pollution problems present in different sectors of a city can be corrected. The next stage in our line of research is to compare the results with international indexes of air quality and generate cartographic time schedules of the analysed area. In this way we will be able to identify the critical spots and make the necessary corrections by pre-planning circuits and frequencies of UPTS public transport.

#### REFERENCES

- [1] Querol X, Alastuey A, Rodríguez S, Viana M, Artiñano, B, Salvador P, et al. *Levels of PM in rural, urban and industrial sites in Spain*. The Science of Total Environment; 334-5, 359-376, 2004.
- [2] Who Working Group, (2000). Quantification of health effects of exposure to air pollution. Regional Office for Europe, Copenhagen. En: <http://www.euro.who.int/document/e74256.pdf> 17/09/2009
- [3] Alonso E, Martínez T, Cambra K, López L, Boldo E, Zorrilla B., Evaluación en cinco ciudades españolas del impacto en salud de la contaminación atmosférica por partículas. Proyecto europeo APHEIS. Revista Española de Salud Pública. 79, 297-308, 2005.
- [4] Díaz J, García R, Ribera P, Alberdi J., Hernández E, Pajares M. Modeling of air pollution and its relationship with mortality and morbidity in Madrid, Spain. Int Arch Occup Environ Health. 72, 366-376, 1999.
- [5] Bose, R. y Srinivasachary, V. Policies to reduce energy use and environmental emissions in the transport sector, Energy Policy 25, Elsevier, Amsterdam, 1137-1150, 1997.
- [6] Lenz, H. P., Prüller S. y D. Gruden. *Means of Transportation and their effect on the environment*, in D. Gruden (ed.), The Handbook of Environmental Chemistry Vol. 3, Part T, Traffic and Environment, Springer Verlag, Berlin- Heidelberg, 107-173, 2003.
- [7] Johansson, B. (1995) Strategies for reducing emissions of air pollutants from the Swedish transportation sector, Transpn. Res.-A. 29, Elsevier, Amsterdam, 371-385.

- [8] Machado, A., Garcia N., Huertas, JI. (2004) Air emissions inventory of the public transport in Maracaibo Municipality: Part I: Passenger car. *Rev. Téc. Ing. Univ. Zulia*, vol.27, no.3, 202-209. ISSN 0254-0770.
- [9] Zahran, E. S. M., (2013) A Novel Approach to Improve the Air Quality Predictions of Air Pollution Dispersion Modelling Systems. *International Journal of Environmental Research*, Article 20, Volume 7, Number 1, Page 205-218.
- [10] Zahran, E. S. M., Smith, M., Bennett, L., (2013) 3D Visualization of Traffic-Induced Air Pollution Impacts of Urban Transport Schemes. *Journal of Computing in Civil Engineering*, 27(5), 452–465.
- [11] Sinha, K. C. Sustainability and urban public transportation, *Journal of Transportation Engineering* 129, American Society of Civil Engineers, Washington, 331-341, 2003.
- [12] Hine, J., Rye T. y Hulse M. (2000) Using land-use planning to manage transport demand: a survey of Scottish experience. *Local Environment* 5, Taylor and Francis, London, 33-53.
- [13] Mceldowney, M., T. Ryley, M. Scott Y A. Smyth (2005) Integrating land-use planning and transportation in Belfast: a new policy agenda for sustainable development. *Journal of Environmental Planning and Management* 48, 507-526 pp.
- [14] Rodenburg, C. A., Ubbels B. y Nijkamp P. (2002) Policy scenarios for achieving sustainable transportation in Europe, *Transport Reviews* 22, Taylor and Francis, London, 449-472.
- [15] Sperling, D. (2004) Environmental impacts due to urban transport, en H. Nakamura, Y. Hayashi y A.D. May (Eds.), *Urban Transport and the Environment. An International Perspective*, Elsevier, Oxford, 99-189.
- [16] Corvalán R., Gherardelli C., Tolvet S., Rey S. (2009). Analysis of the Potential Environment Impact of an Emission Compensation System: The Case of the Metropolitan Region of Santiago, Chile. *Revista Ciencia Abierta*, número 31. En <http://cabierta.uchile.cl/revista/15/articulos>, Octubre, 2009.
- [17] Jiménez F., Racero J., Villa G., García J., (2004). Diseño de algoritmos de calibración de matrices origen destino a partir del análisis del proceso de asignación de tráfico. VIII Congreso de Ingeniería de Organización. Leganés, España.
- [18] Martínez Pérez, P.J. y Monzón De Cáceres A. Informe sobre transporte y medio ambiente. I. Elorrieta y M. San Miguel (Eds.). Centro de Publicaciones Secretaría General Técnica Ministerio de Medio Ambiente, Madrid, pp. 108, 2005.
- [19] Martínez Pérez, P.J.; Monzón, A. Seguimiento de la integración del transporte y el medio ambiente en España. M+A. *Revista Electrónica de Medioambiente*, 3, 90-102., May, 2009.
- [20] Shir C.C. y Shieh L.J., (1974). A Generalized Urban Air Pollution Model and Its Application to the Study of SO<sub>2</sub> Distributions in the St. Louis Metropolitan Area. *Journal of Applied Meteorology* Article, 185–204, 1974.
- [21] Hong Huang, Yoshiaki Akutsu, Mitsuru Arai, Masamitsu Tamura. A two-dimensional air quality model in an urban street canyon: evaluation and sensitivity analysis. *Atmospheric Environment*, Volume 34, Issue 5, 689-698. Elsevier Science Ltd, 2000.
- [22] Vienneau, D., de Hoogh, K. and Briggs, D.J. A GIS-based method for modelling info air pollution exposures across Europe. *Science of the Total Environment* 408, 255-266, 2009.
- [23] Pasky Pascual, Neil Stiber, Elsie Sunderland, Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models, Office of Science Policy, Office of Research and Development, <http://www.modeling.uga.edu>, 2003.
- [24] CERC Cambridge Environmental Research Consultants, ADMS-Roads Comprehensive software for modelling road traffic pollution <http://www.cerc.co.uk/environmental-software/ADMS-Roads-model.html>, 2013
- [25] Fernando Jiménez Canelada, Jesús Racero Moreno, Gabriel Villa Caro, José Manuel García Sánchez, Diseño de algoritmos de calibración de matrices origen destino a partir del análisis del proceso de asignación de tráfico. VIII Congreso de Ingeniería de Organización. Leganés, España, 2004.
- [26] European Environment Agency, COPERT II Computer Programme to calculate Emissions from Road Transport. Methodology and Emission Factors, Technical Report No. 6, [www.eea.europa.eu/publications/Technical\\_report\\_No\\_50](http://www.eea.europa.eu/publications/Technical_report_No_50), EEA, Copenhagen, 1998.
- [27] EMEP/CORINAIR Emission Inventory Guidebook, European Environment Agency, <http://www.eea.europa.eu/publications/EMEPCORINAIR5>, Published: Dec 06, 2007.
- [28] LAT/AUTH, University of Limerick, Methodologies for Estimating Air Pollutant Emissions From Transport - MEET, Deliverable No 3: Final data structure of road emission factors, TÜV Rheinland, Köln, Germany, (1997).